Turbulence intensity retrieval in precipitation via optimal estimation using polarimetric radar

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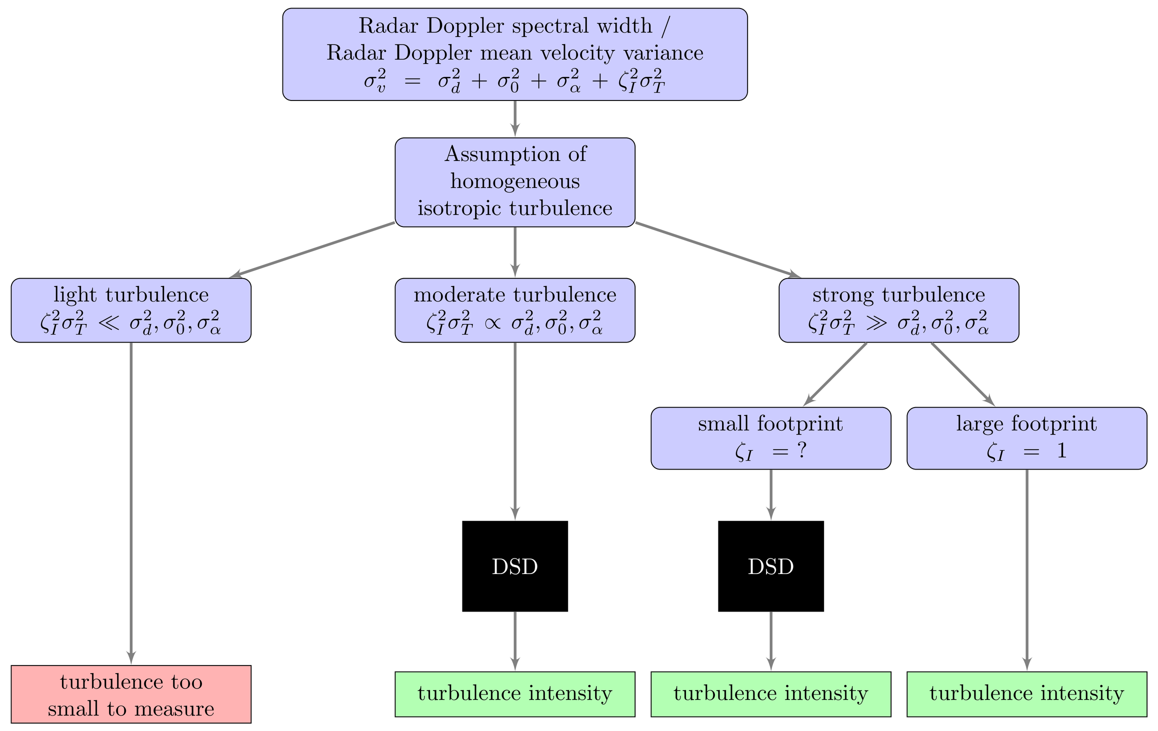
Objectives

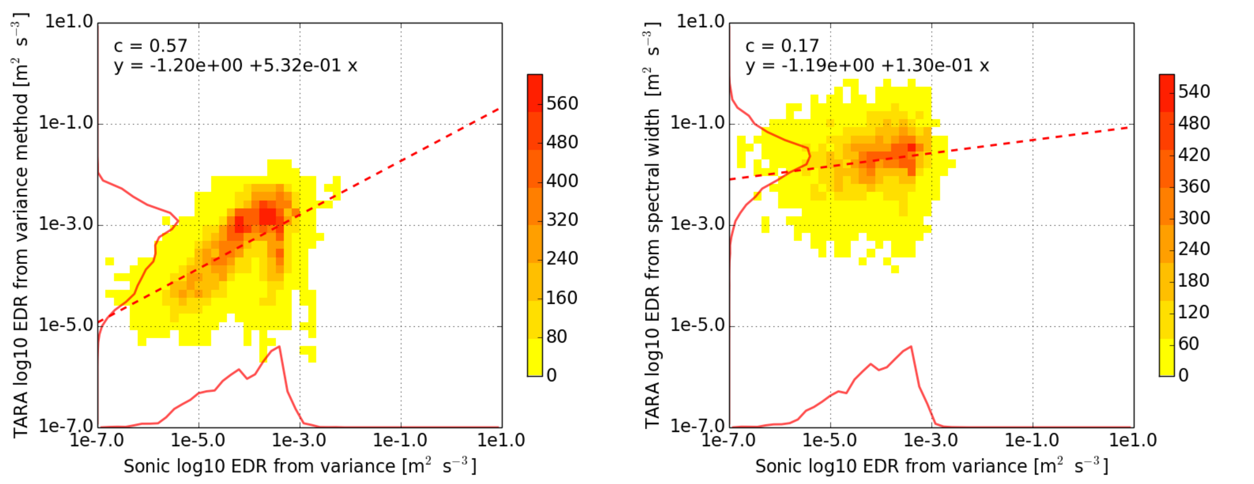
- Develop a radar forward model, where as a function of turbulence intensity, a parametric or stochastic solution can be chosen.
- Develop a generalized methodology to retrieve the turbulence intensity from polarimetric radar data.

Introduction

- The polarimetric profiling radar at a slant elevation angle is a promising sensor for remote sensing of particle characteristics (Bringi and Chandrasekar, 2004).
- For an accurate turbulence intensity retrieval in rain, often the drop size distribution is crucial.



Relevance of the DSD on turbulence intensity retrievals. In this schematic σ_v, the Doppler spectral width or the velocity standard deviation, is the measurement. The contributors to this measurement are antenna motion σ_α, hydrometeor fall speeds σ_d, hydrometeor orientations and vibrations σ_0 and turbulence σ_T, where ζ_I is the hydrometeor inertia correction. Note that the turbulence contribution scales with the spatial scale $\sigma \propto L^{1/3}$.



Scatter density plots of eddy dissipation rate (EDR) from profiling radar (TARA) versus a sonic anemometer. left) EDR from 10 min. of mean Doppler velocities and right) EDR from spectral width, with a correction for fall speed width (Yanovsky et al., 2015). In these retrievals no polarimetric information is used.

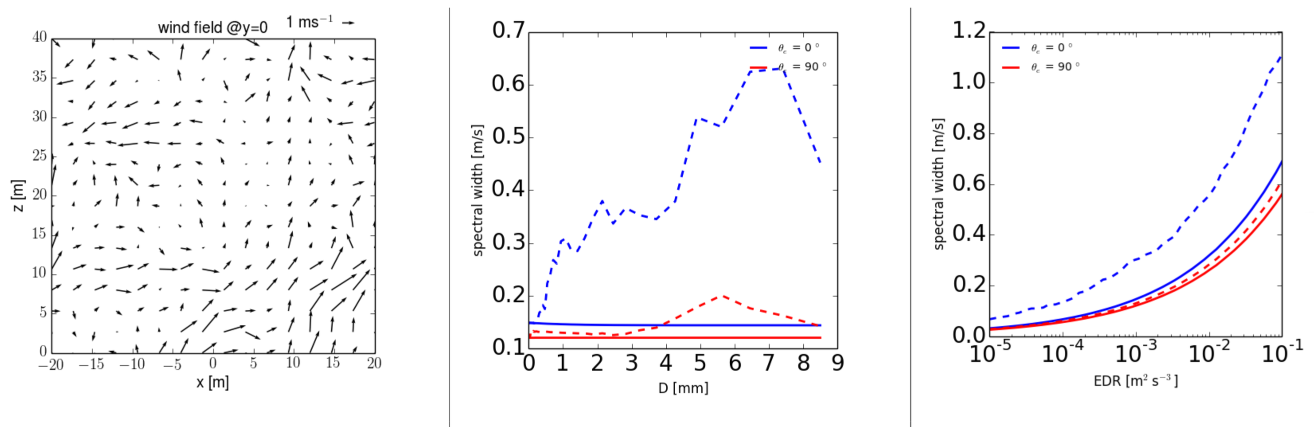
Simulation of the inertia effect

- We estimate the effect of droplet inertia on the radar measurements by solving the equations of motion for an ensemble of droplets for a backward trajectory.
- We use 3D stochastic turbulence from Mann (1998).
- The inertial velocity term $\vec{v}_p'$ is assumed to be small in comparison to the total particle velocity.
- The particle velocity is written as:

$$\vec{v}_p = \vec{v}_t + \vec{v}_a + \vec{v}_p' \tag{1}$$

where $\vec{v}_t$ is the terminal fall velocity and $\vec{v}_a$ the air velocity. The solution is found by solving the equations of motion for a small trajectory, e.g. for the z-direction:

$$\frac{dv_{p,z}}{dt} = F_g - F_b - F_{d,z} = \eta_{I,z}v_t^2 - \eta_{I,z}(v_{p,z} - v_{a,z})^2. \tag{2}$$



stochastic turbulence | $\epsilon = 10^{-3}$ | $D = 1$ mm

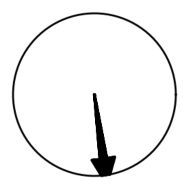
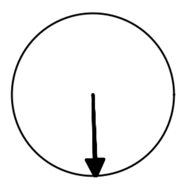
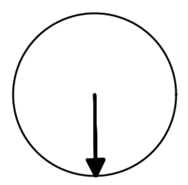
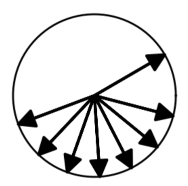
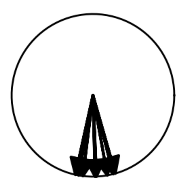
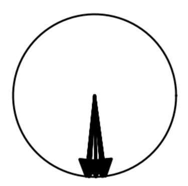
simulation of inertia Doppler spectral width with (striped) and without (line) the inertia effect.

Relevance of inertia

- The inertia effect can double the spectral width.
- The inertia effect is more relevant for horizontally pointed radar.

Forward model

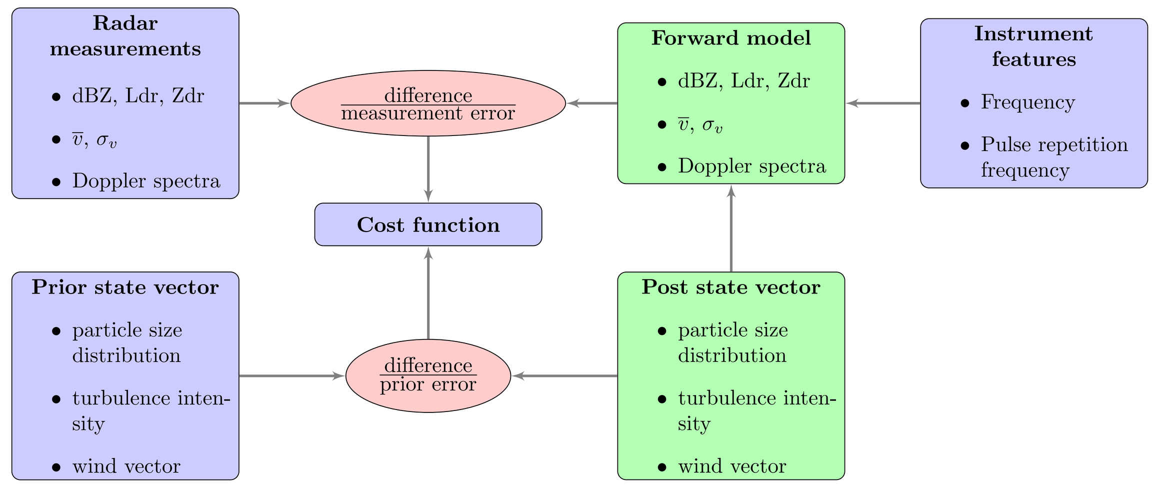
- An ensemble of particles is used to cover a spatial distribution, matching the radar resolution volume and a size distribution.
- Cross sections from Mishchenko (2000) and terminal fall velocities from Khvorostyanov and Curry (2005) are used.
- The particle symmetry axis is oriented parallel to the particle motion.
- Turbulence is modelled as an ensemble of isotropic vectors, with the standard deviation of radials speed from White et al. (1999).

	0.1 mm	1.0 mm	5.0 mm
light turbulence, $\sigma = 0.1$ ms^{-1}.			
heavy turbulence, $\sigma = 2.0$ ms^{-1}.			

An ensemble of isotropic vectors. Shown are the orientations of the ensemble, which depend on the relative sizes of the terminal fall speed, air velocity and turbulence velocity.

Optimal estimation

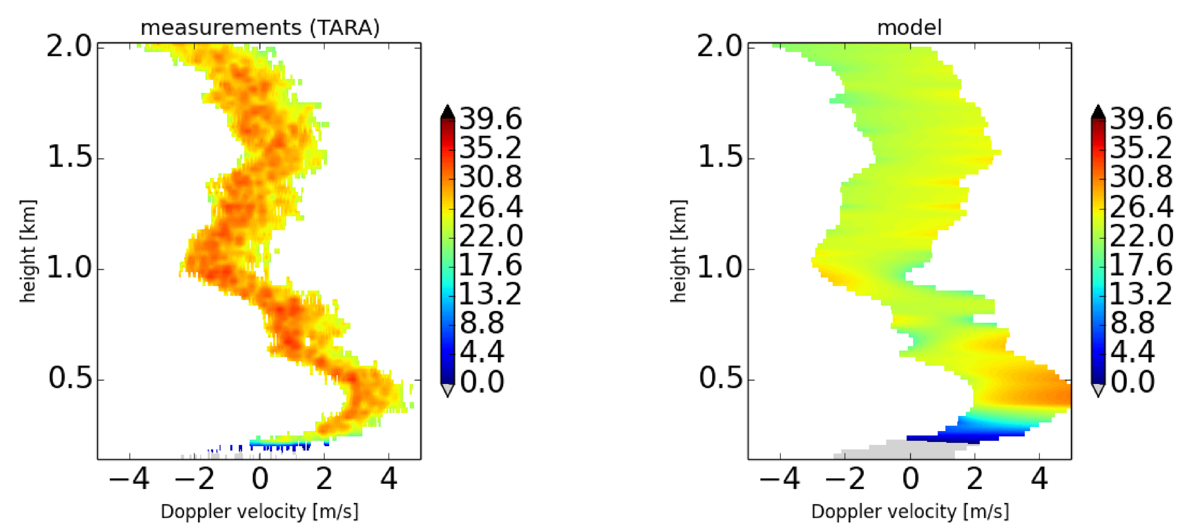
- In optimal estimation the model parameters are fitted to the measurements via minimization of the cost function.
- The cost function consists of differences in measurements space and parameter space. We use the NLopt package for minimization.



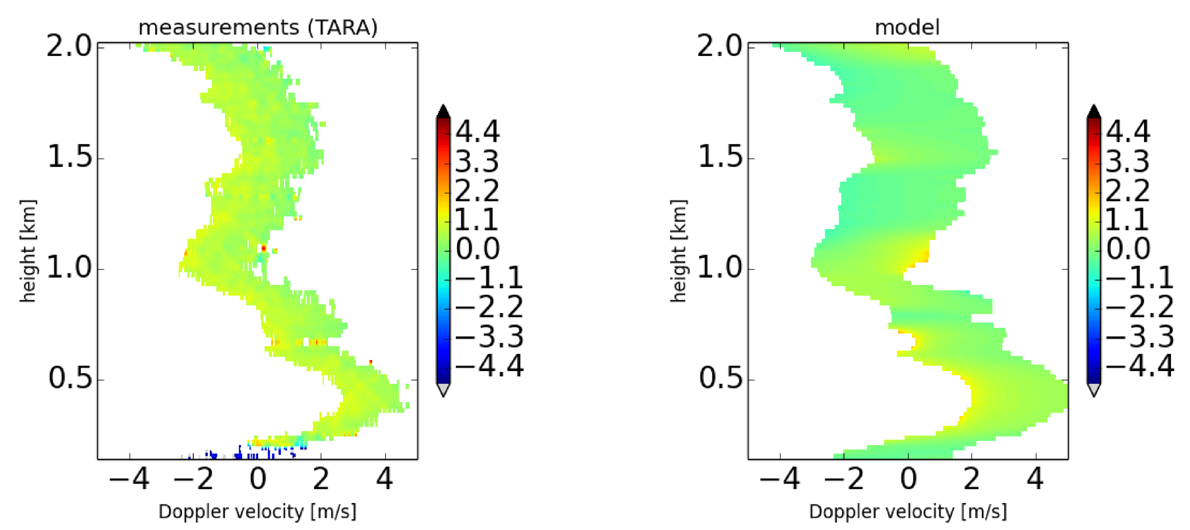
Optimal estimation retrieval technique

Measurements vs. forward model

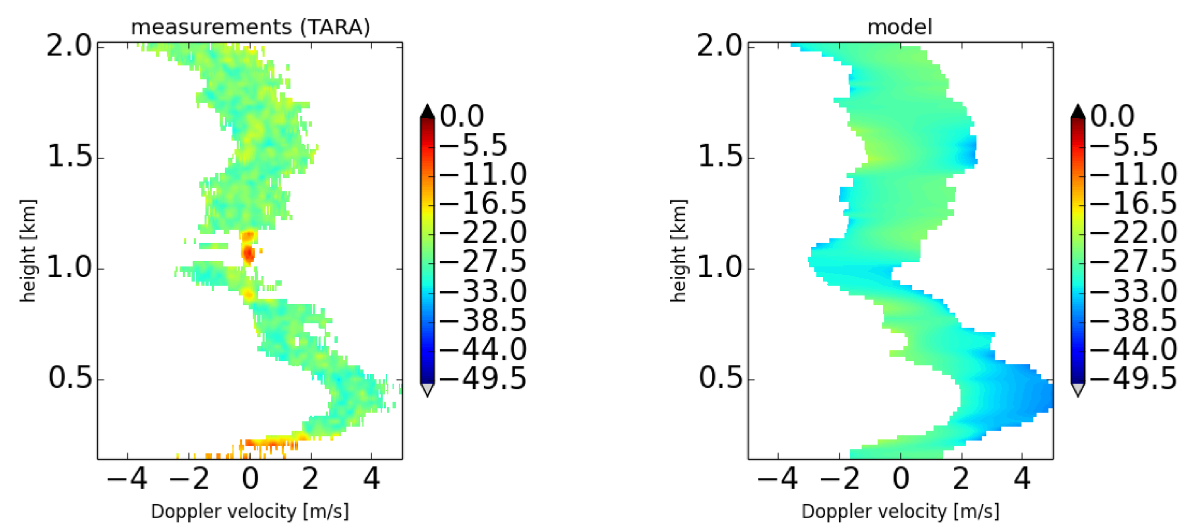
hh Doppler spectrum, dBZsm^{-1}



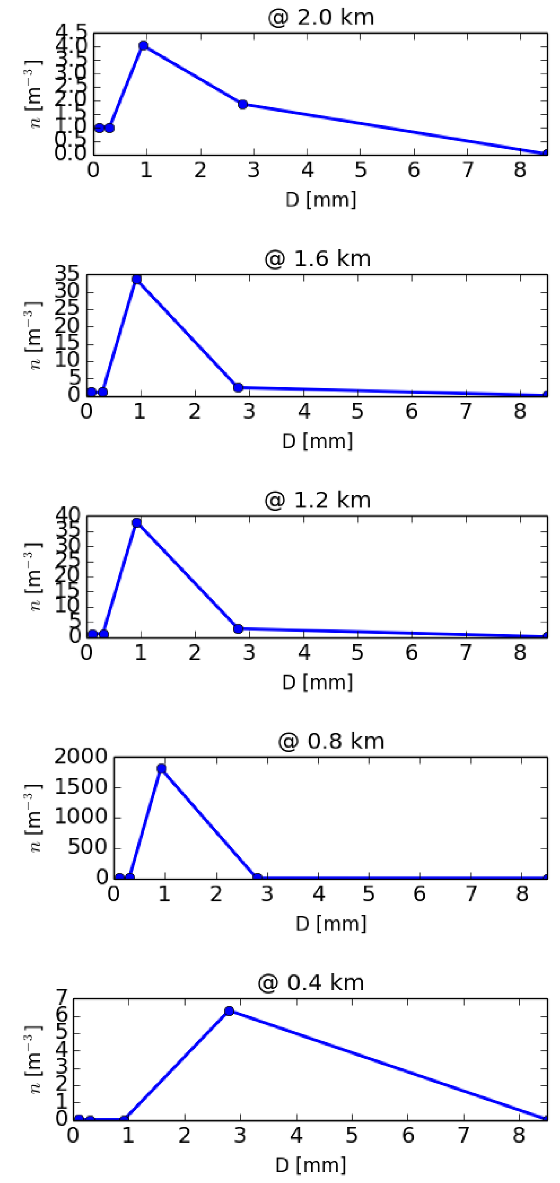
specific differential reflectivity, dBZdr

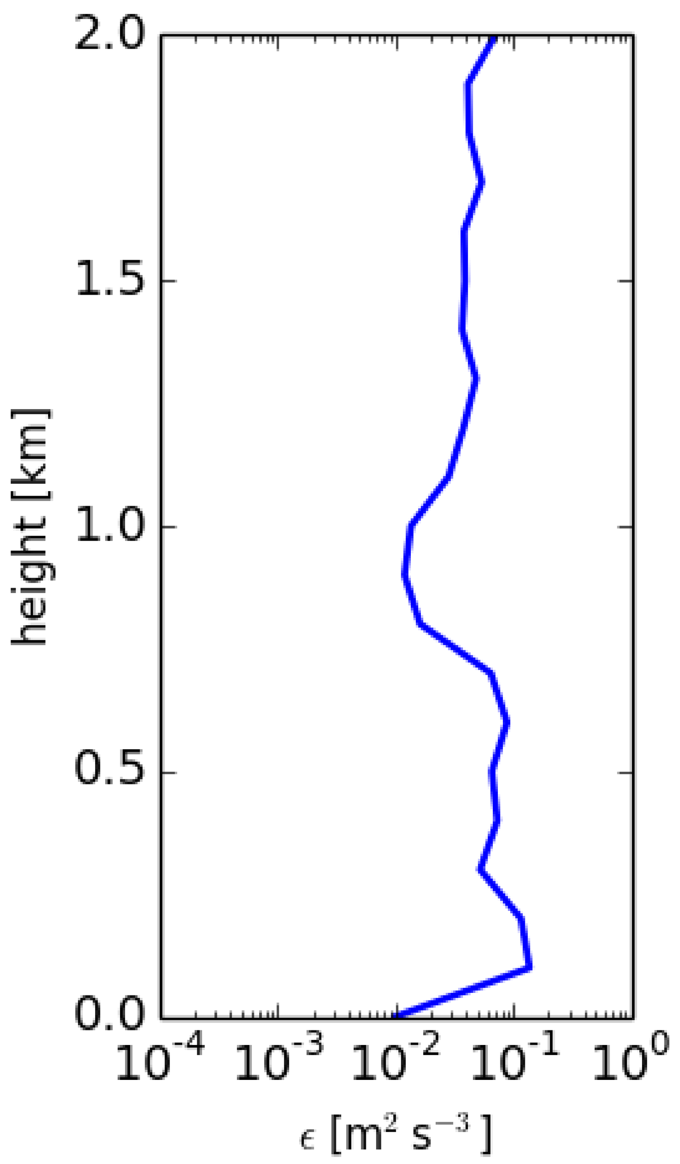


specific linear depolarization ratio, dBLdr



Retrieved profiles





Drop size distribution | **Turbulence intensity**

Discussion

- A novel forward model is proposed for retrievals of turbulence intensity profiles, which takes the orientations of particles into account.
- The inertia effect increases the Doppler spectral width.
- Error estimation of the posterior size distribution will improve the interpretation of radar measurements.

Additional Information

Download The model Zephyros, a package for radar simulations and retrievals of wind and turbulence, under development, is written in C with interfaces to Python and Matlab and can be downloaded from:

`https://github.com/albertoudenijhuis/zephyros0.4`

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